Astronomy & Astrophysics manuscript no. sygroupfinal2
October 31, 2012

The environment of AGNs and the activity degree of their surrounding galaxies ⋆

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Received 2011; accepted 2012

ABSTRACT

Aims. We present results of a comprehensive spectral study on the large-scale environment of AGNs based on Sloan Spectroscopic Survey data.
Methods. We analyzed the spectra of galaxies in the environment of AGN and other activity classes up to distances of 1 Mpc.
Results. The mean Hα and [O III] λ5007 line luminosities in the environmental galaxies within a projected radius of 1 Mpc are highest around Seyfert 1 galaxies, with decreasing luminosities for Seyfert 2 and HII galaxies, and lowest for absorption line galaxies. Furthermore, there is a trend toward Hα and [OIII] luminosities in the environmental galaxies increasing as a function of proximity to the central emission line galaxies. There is another clear trend toward a neighborhood effect within a radius of 1000 kpc for the AGN and non-AGN types: Seyfert galaxies tend to have the highest probability of having another Seyfert galaxy in the neighborhood. HII galaxies tend to have the highest probability of having another HII galaxy in the neighborhood, etc. The number of companions within 1000 kpc is inversely correlated with the Hα, [O III] λ5007, as well as with the continuum luminosities of the central galaxies, regardless of whether they are of Seyfert, HII, or absorption line types.

Key words. Galaxies: active – Galaxies: Seyfert – Galaxies: starbursts – Galaxies: interactions – Galaxies: statistics

1. Introduction

It has been known for many decades that the morphology of galaxies is correlated to the number of galaxies in their environment. For instance, Oemler (1977) noted that the population of elliptical, spiral, and S0 galaxies varies with the mean density of galaxy clusters. This so-called morphology-density relation (MDR) might be explained by the slow stripping of gas from spiral galaxies (e.g. van der Wel et al. 2010).

In addition to this finding, astronomers have been debating since more than 20 years whether the environment of active galactic nuclei (AGN) or starburst galaxies is different from that of inactive galaxies. This idea is based on the concept that nuclear activity, as well as starburst activity in galaxies, is triggered by galaxy interactions and/or that in general the environment of active/non-active galaxies is different for different types (e.g. early papers by Hutchings et al. 1984, Dahari 1985, Keel et al. 1985, Bushouse 1990, Byrd et al. 1987).

In the meantime it has been accepted by most astronomers that starburst activity in galaxies is triggered by tidal interactions (e.g. Woods & Geller 2007, Shardha et al., 2009 and references therein). However, the concept of tidal triggering for the generation of nuclear Seyfert/Quasar activity is less clear. Many studies have been undertaken to investigate the environmental density of active galaxies and to compare it with inactive and/or starburst galaxies. Some authors claim an underdensity of bright galaxies in the environment of Seyfert galaxies/quasars (e.g. Constantin & Vogeley, 2006; Lietzen et al., 2009), while others find a similar clustering strength in the environment of AGN and inactive galaxies on scales of less than 100 kpc up to scales larger than a few Mpc (e.g. Li et al., 2006).

Other studies have investigated the influence of large-scale structures on the color distribution of AGN host galaxies. Silverman et al. (2008) demonstrate that the color distribution of AGN host galaxies is highly dependent on the influence of 10 Mpc scale structures. Coldwell et al. (2009) report that the neighborhood of their blue AGN sample is indistinguishable from their inactive counterpart, while the red AGN environments show an excess of blue star-forming galaxies.

Furthermore, it is under debate whether the environment is different for different types of AGN. Based on the unified model of AGN one would expect no difference in the environment of Seyfert 1 and Seyfert 2 galaxies. Corresponding to this picture, Sorrentino et al. (2006) extracted galaxies in the redshift range $0.05 \leq z \leq 0.095$ from the Fourth Data Release (DR4) of the Sloan Digital Sky Survey (SDSS). They see no difference in the large-scale environment of the two Seyfert types. Koulouridis et al. (2006) and Strand et al. (2008) investigated the environment of Seyfert galaxies having redshifts of $0.004 \leq z \leq 0.036$ and $0.11 \leq z \leq 0.6$, respectively. They, however, find an overdensity of companions around Seyfert 2 galaxies.

Nearly nothing is known about the spectral activity of galaxies in the environment of AGN (Kollatschny & Fricke, 1989, Fricke & Kollatschny, 1989). Here we carry out an in-depth analysis of the spectral activity of the environmental galaxies of 3500 AGN/non-AGN based on Sloan Digital Sky Survey (SDSS) spectra. We investigate the spectral properties of the environmental galaxies up to projected distances of 1 Mpc.

⋆ Based on Sloan Data

Throughout this paper we use $H_0 = 75 km\,s^{-1}\,Mpc^{-1}$. We neglect cosmological corrections on the distances of our galaxies as they are local (z≤0.08).

The paper is organized as follows. The data samples and the algorithms we used to find the number of neighbors are described in Sects. 2 to 4. The results regarding the number of companions and the activity of the environmental galaxies are presented in Sect. 5. A detailed discussion and the conclusion are given in Sect. 6.

2. The SDSS spectroscopic survey

The present environmental study is based on spectra from the Sloan Digital Sky Survey (SDSS) Data Release 5 (DR5; Adelman-McCarthy (2007). The SDSS is a photometric and spectroscopic survey of a quarter of the sky. The SDSS DR5 covers an area of 5740 square degrees. Imaging and positional data are available in the u,g,r,i,z bands for more than 100 million objects. The imaging data are calibrated photometrically and astrometrically.

More than one million spectra are contained in the SDSS DR5. The spectra cover the spectral range $3800 \leq \lambda \leq 9200$ Å with a spectral resolution of $\lambda/\delta\lambda = 1800$. This corresponds to a redshift accuracy of $\sim 170\,km\,s^{-1}$.

3. Definitions of AGN/non-AGN samples

The spectra of our current study were selected from the spectroscopic SDSS survey. First we selected all objects that have been classified as galaxies or quasars. In a second step we restricted ourselves to nearby galaxies/QSOs having redshifts z of less than 0.08 to narrow down the sample. Intrinsically faint environmental galaxies can be studied in detail only in the nearby universe. For detecting faint galaxy companions we limited our sample to central AGN/non-AGN galaxies having g-band fiber magnitudes of at least 18 (for fiber magnitude definitions see Adelman-McCarthy (2007) and references therein). This corresponds to g-band luminosities of e.g. $L=3.2\cdot10^{41}$ erg s^{-1} for z=0.01 and $L=7.4\cdot10^{42}$ erg s^{-1} for z=0.05. Galaxies in the nearby universe (e.g. M100) have a g-band luminosity of $L=1\cdot10^{43}$ erg s^{-1}.

In addition we set the condition that the given line fluxes of Hβ and [O III] λ5007 be higher than 10^{-17} $erg\,s^{-1}\,cm^{-2}$ to exclude low signal-to-noise spectra from our emission line sample. The absorption line galaxies have negative Hα and Hβ line fluxes.

We generated two spectroscopic Seyfert samples (Seyfert 1, Seyfert 2 galaxies) and two control samples (HII galaxies, absorption line galaxies) for the present study of the AGN environment – based on the SDSS spectroscopic survey.

Seyfert 1 galaxies are identified on the basis of their broad Balmer emission lines in the SDSS spectra. The other active galaxy types were classified on the basis of their emission line ratios of [O III] λ5007, Hβ, [N II] λ6583, and Hα lines in the diagnostic diagram of Kauffmann et al. (2003). We executed the following queries for selecting individual central galaxy types from the SDSS spectra:

- Seyfert 1 galaxies were by definition those galaxies having emission line widths (FWHM) broader than 1000 $km\,s^{-1}$.
- Seyfert 2 galaxies were selected on the basis of the line intensity ratios of the emission lines [O III] λ5007, Hβ, [N II] λ6583, and Hα. They are defined by
$\log([\mathrm{O\,III}]\,\lambda5007/\mathrm{H}\beta) > 0.61/\{\log([\mathrm{N\,II}]/\mathrm{H}\alpha) - 0.05\} + 1.3$ and $[\mathrm{NII}]/\mathrm{H}\alpha < 1.1220$.
- HII galaxies are defined by
$\log([\mathrm{O\,III}]\,\lambda5007/\mathrm{H}\beta) < 0.61/\{\log([\mathrm{N\,II}]/\mathrm{H}\alpha) - 0.05\} + 1.3$.
- Absorption-line galaxies show Hα and Hβ in absorption.

The galaxies in the AGN/non-AGN environment were divided by us into further subclasses with respect to their emission/absorption line intensities:

- The narrow-line AGN were divided into Seyfert 2 and LINER types. The dividing line between these two types is given by the subsequent line intensity ratios in the diagnostic diagram:
$\log([\mathrm{O\,III}]\,\lambda5007/\mathrm{H}\beta) = \log([\mathrm{N\,II}]/\mathrm{H}\alpha) \cdot \tan(25°) + 0.45 \cdot \tan(25°) - 0.5$
(Kauffmann et al., 2003; Kewley et al., 2006).
- $H\alpha$ emission line galaxies exhibit clear $H\alpha$ emission lines.
- Absorption line type 1 galaxies (Abs1) show Balmer lines in absorption with weak additional emission lines, such as [O III] and [N II] emission lines.
- Absorption line 2 galaxies (Abs2) display the Balmer lines in absorption, along with neither [O III] nor [N II] lines in emission.

Based on the criteria given above we established four environmental samples around four different types of central galaxies from the spectroscopic SDSS survey: two Seyfert samples consisting of 114 central Seyfert 1 and 1480 Seyfert 2 galaxies, as well as two control samples consisting of 1406 central HII galaxies and 415 absorption line galaxies (see Table 1). The mean g-band continuum luminosities ($\log \bar{L}$ = 43.3 - 43.8 erg s^{-1}) of the central galaxies are equal within a factor of three in all samples with $\bar{L}_{Sey1} = 4.3 \cdot 10^{43}$ erg s^{-1} and $\bar{L}_{Sey2} = 6.5 \cdot 10^{43}$ erg s^{-1}.

SDSS spectra exist only for a subsample of the SDSS photometric survey because of the limited number of fibers, as well as because of the flux limits for getting spectra with sufficient signal-to-noise ratio. There are typically five time more galaxies in the environmental regions - based on their colors - in the photometric galaxy survey in comparison to the number of spectra that have been taken with SDSS.

4. AGN environment and reference samples

We inspected all SDSS spectra of the AGN/non-AGN companion galaxies within a projected radius of 1000 kpc of the 3,415 central galaxies (Table 1). The projected distance has been calculated by us by means of the coordinates and the redshift of the central galaxy. Furthermore, only those galaxies were selected as physical neighbors to the central galaxy that have redshifts within z = 0.003 of the central galaxy or have radial velocities within ±800 $km\,s^{-1}$, respectively (e.g. Madore et al., 2004).

In addition we inspected the SDSS direct images if companion galaxies to other galaxies were picked out by our SDSS DR5 query within a projected distance of 15 kpc. We verified by eye on the direct images whether the listed objects were really distinct galaxies. In most cases the listed emission line spectra were generated in HII regions within the host galaxies.

All together we determined the number of companion galaxies in the environment of the 3,415 central galaxies (Seyfert 1, Seyfert 2, H II galaxies, absorption line galaxies) and analyzed the Hα and [O III] λ5007 line intensities of 21,469 environmental galaxies.

5. Results

5.1. The number of AGN/non-AGN galaxies and their companions

In Table 1 we present the different activity types of central galaxies, their numbers, the total amount of companions detected

Table 1. Number of environmental galaxies within 1 Mpc.

Activity Type of centr. gal.	Number of centr. gal	Number of comp. gal.	Average No. of comp. gal.
Sey1	114	514	4.51
Sey2	1,480	7,867	5.32
HII	1,406	7,456	5.30
Abs	415	5,632	13.57
	3,415	21,469	

Table 2. Number of environmental galaxies within 0 – 0.2 Mpc, as well as within spherical shells of 0.4 – 0.6 Mpc, and 0.8 – 1 Mpc.

Central gal.	Comp. 0–0.2	avg No 0–0.2	Comp. 0.4–0.6	avg No 0.4–0.6	Comp. 0.8–1	avg No 0.8–1.
Sey1	70	0.61	109	0.96	111	0.97
Sey2	1046	0.71	1659	1.12	1786	1.21
HII	938	0.67	1559	1.11	1685	1.20
Abs	612	1.47	1189	2.87	1077	2.60

in a projected radius of 1000 kpc, and the average number of companions per central galaxy. With an average number of 4.5, Seyfert 1 galaxies have the fewest companion galaxies within a projected distance of 1000 kpc. Seyfert 2 Galaxies and HII galaxies have about an equal number of companions with 5.3. Absorption line galaxies have with 13.6 by far the most companions.

In addition we counted the galaxies within spherical shells around the central galaxies to test whether the relative number of companions is distinct for different types of central galaxies as a function of distance. The absolute number, as well as the average number of companion galaxies (based on the numbers in Table 1), is given in Table 2 for different spherical shells. The absolute number of companions is increasing in the shells as a function of radius because the volumes are becoming systematically bigger. However, the general difference regarding the average number of companions for the various types of central galaxies is distance independent.

5.2. The number of companion galaxies as function of the Hα, [O III] λ5007, as well as continuum luminosities of the central galaxies

We identified the number of companion galaxies as a function of the Hα, [O III] λ5007, as well as g-band continuum luminosities of their central galaxies. We determined this for all 21,469 galaxies within the projected radius of 1 Mpc in the environment of the four different types of central galaxies (Seyfert 1, Seyfert 2, HII, absorption line gal.). We summed up the number of companion galaxies within bins of one magnitude, respectively, of the Hα, [OIII], and g-band luminosities. We set an upper luminosity limit of $L = 10^{34}\,erg\,s^{-1}$ whenever the emission lines were too weak to be detected in the galaxy spectra or when the galaxy spectra were too noisy.

Finally we divided the relative numbers of environmental galaxies into four separate classes (within the projected radius of 1 Mpc):
- the central galaxy has 0 to 3 companions,
- the central galaxy has 4 to 5 companions,
- the central galaxy has 6 to 8 companions,
- the central galaxy has more than 8 companions.

Table 3. Relative frequency (in percent) of individual activity types in the neighborhood of Seyfert, HII, and absorption-line galaxies.

Central gal.	Sey	LINER	HII	HαEm	Abs1	Abs2
Sey1	19.7	1.2	38.3	14.2	6.0	20.6
Sey2	15.1	0.8	46.0	11.6	6.3	20.2
HII	14.0	0.5	50.8	10.9	5.6	18.3
Abs.	8.9	0.5	24.4	10.2	8.9	47.2

We present in Fig. 1 the numbers of galaxy companions as a function of internal Hα (Fig. 1a-c), [O III] λ5007 (Fig. 1d-f), and g-band (Fig. 1g-j) luminosities for all the different types of central galaxies. These numbers are summed up within projected radii of 1 Mpc around the central galaxies. Given are the relative numbers in percent for the individual magnitude bins.

The number of companion galaxies – within the projected radius of 1 Mpc of our central galaxies – is inversely correlated with the Hα, [OIII] and continuum luminosities. This means that the higher the emission line and/or continuum luminosity of a galaxy, the lower the number of companions. The same trend appears in all our four galaxy samples (central Sey 1, Sey 2, HII galaxy, absorption line galaxy) independently. The given results shown in two Seyfert 1 luminosity bins of Fig. 1 (log L[OIII]= 37 (Fig 1.d) and log L_{cont}= 41 (Fig 1.g)) are not significant because they are caused only by one galaxy. This general trend in Fig. 1 is superimposed on the second trend that different activity types of galaxies lie in different dense environments (see Table 1).

The number of companion galaxies would decrease by 18 percent when we defined physical neighbors by having radial velocities within $\pm 600\,km\,s^{-1}$ (instead of $\pm 800\,km\,s^{-1}$) to the central galaxies. However, the general trends remain the same.

5.3. The activity type of AGN/non-AGN companion galaxies

We present in Table 3 and Fig. 2 the relative numbers of companion galaxies (in percent) belonging to the different activity types as a function of activity degree of the central AGN/non-AGN galaxy. The neighbors are divided into additional subtypes as defined in Section 3.

HII galaxies are the most common type except in the environment of absorption-line galaxies. Pure LINER spectra are rarest. There is a clear trend by a neighborhood effect within the projected radius of 1 Mpc toward the AGN and non-AGN types: Seyfert galaxies tend to have the highest probability of having another Seyfert galaxy in the neighborhood. HII galaxies tend to have the highest probability of having another HII galaxy in the neighborhood. And finally, absorption-line galaxies tend to have the highest probability of having another absorption-line galaxy in their neighborhood.

5.4. Hα and [O III] λ5007 emission line luminosities in the spectra of AGN/non-AGN companions

The Hα and [OIII] line luminosities in the environment of Seyfert 1, Seyfert 2, HII, and absorption line galaxies are shown in Figs. 3 and 4 as a function of projected distance to the central galaxy. We are studying whether emission line intensities in

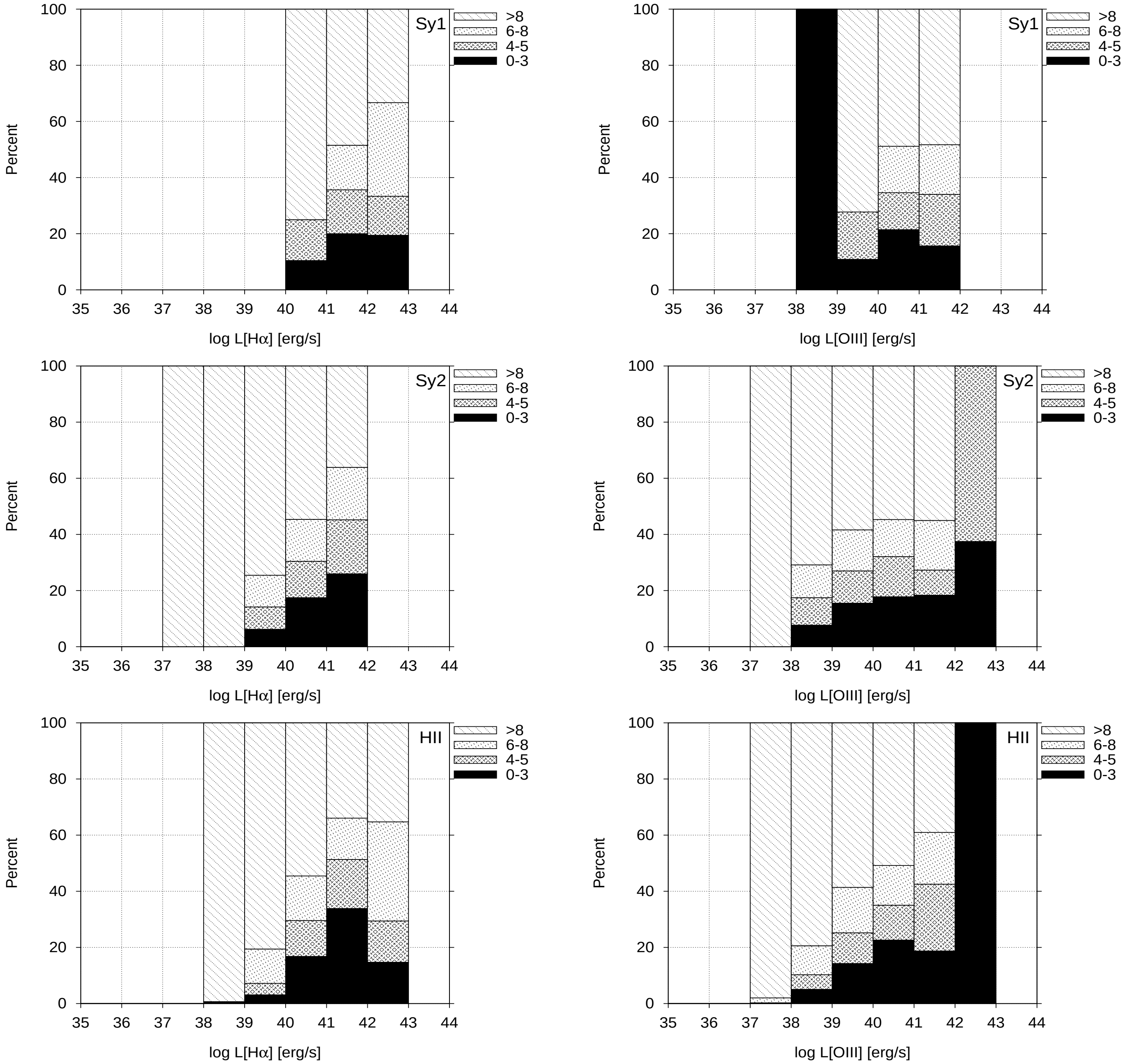

Fig. 1 a-f Relative number of neighboring galaxies (divided into four companion classes: 0-3, 4-5, 6-8, >8 companions) as a function of the Hα and [O III] λ5007 line luminosities (divided into luminosity bins) of the central Seyfert 1, 2, and HII galaxies.

neighboring galaxies are a function of distance to the central object and whether this relation depends on the activity degree of the central galaxy. The line intensities in these figures are given on a logarithmic scale.

The mean Hα and [O III] λ5007 luminosities of the central AGN/non-AGN galaxies, along with of their environmental galaxies within 1 Mpc, are presented in Table 4. Those galaxies showing only upper Hα and [OIII] line luminosity limits of $L = 10^{34}\, erg\, s^{-1}$ in their spectra were not considered for the determination of the mean values. The central Seyfert 1 galaxies exhibit the highest mean Hα and [OIII] line luminosities in their spectra. Seyfert 2 and HII galaxies emit Hα and [OIII] lines that are one magnitude fainter on average.

Considering the environmental galaxies there are two general trends. The environmental galaxies around both Seyfert 1 and Seyfert 2 galaxies emit the highest internal Hα and [O III] λ5007 line luminosities. Seyfert 1 environmental galaxies exhibit mean luminosities of $log\, L = 39.64\, erg\, s^{-1}$ in Hα and $log\, L = 38.94\, erg\, s^{-1}$ in the O[III] line. The mean line luminosities of the companions are lower for Seyfert 2 and HII galaxies. The lowest mean Hα and [OIII] line luminosities of $log\, L = 39.13\, erg\, s^{-1}$ in Hα and $log\, L = 38.14\, erg\, s^{-1}$ in the O[III] line exhibit the companions of the central absorption line galaxies.

The second result is to be seen in the line luminosities of the environmental galaxies considering the projected distance to the central AGN/HII galaxy. There is a trend toward the Hα and [OIII] luminosities in the environmental galaxies becoming stronger when they are located closer to the central emission line galaxy. This observation is even diluted by the fact that we con-

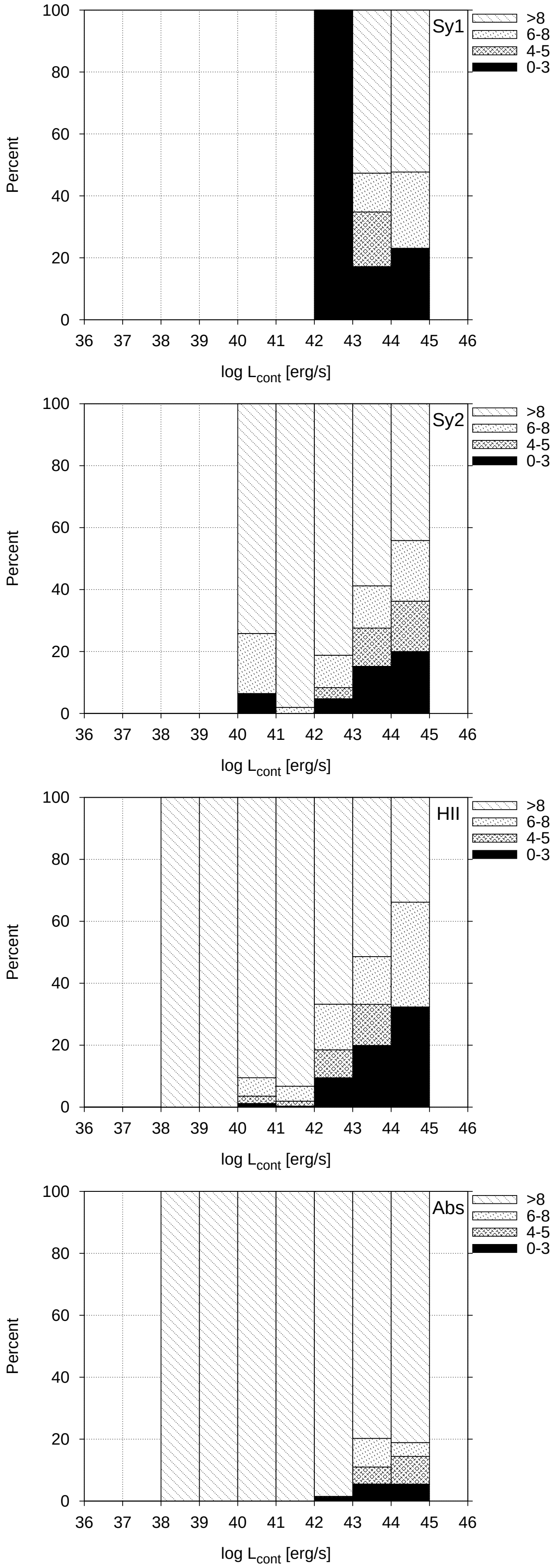

Fig. 1 g-j. Same as Fig. 1 a-f: Relative number of neighboring galaxies for g-band continuum luminosity bins of the central Seyfert 1, 2, HII, and absorption line galaxies.

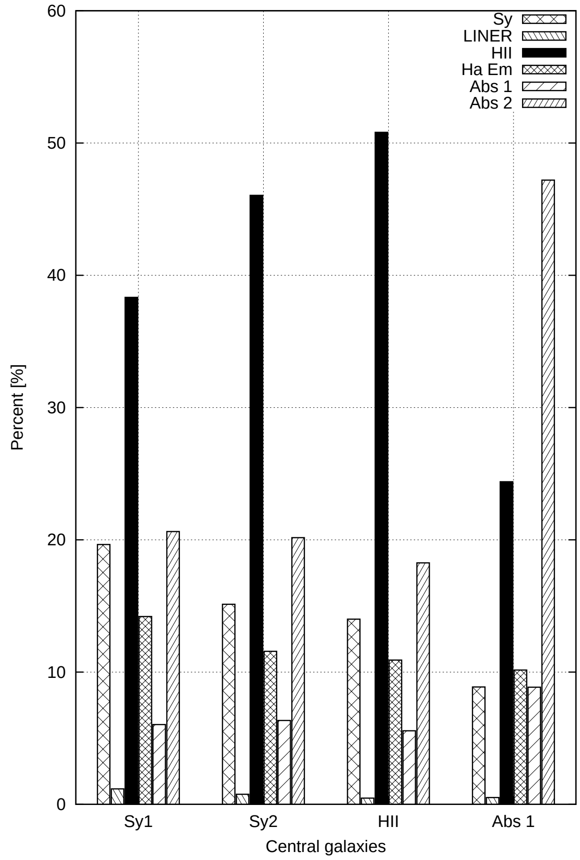

Fig. 2. The spectral activity type of neighboring galaxies as a function of the activity degree of the central galaxy.

sider neighborhood galaxies at projected distances from the central galaxies. Galaxies with small projected distances to the central galaxy might be at large background or foreground distances in reality. Environmental galaxies around absorption line galaxies show the opposite trend to the central Seyfert and HII galaxies: Here the Hα and [OIII] luminosities of the environmental galaxies are increasing as a function of projected distance to the central absorption line galaxy. This is evidence for the morphology density relation that has been mentioned in the introduction.

Figure 5 again demonstrates the trend toward increasing/decreasing activity by the companion galaxies as a function of projected distance to the central galaxy. Here the line intensities are plotted on a linear intensity scale. The line intensities are binned over intervals of 50 kpc projected distance. The companions of the Seyfert 1 galaxies are not considered in these figures since their quantity is statistically not that significant. One can see the clear trend for the mean Hα and [OIII] luminosities of the Seyfert 2 and HII companions to increase toward the central galaxy by a factor of two to four. Again one has to consider the dilution factor of the central foreground and background galaxies. The increasing/decreasing activity begins at projected distances of 200 – 400 kpc. The rise is steeper for HII galaxies than for Seyfert 2 galaxies. The central absorption line galaxies show the opposite trend. Here the mean line intensities of the companions increase by a factor of two over a distance of 1 Mpc.

The log of the mean Hα and [OIII] luminosities in the environmental galaxies is listed in Table 5. It is given for different

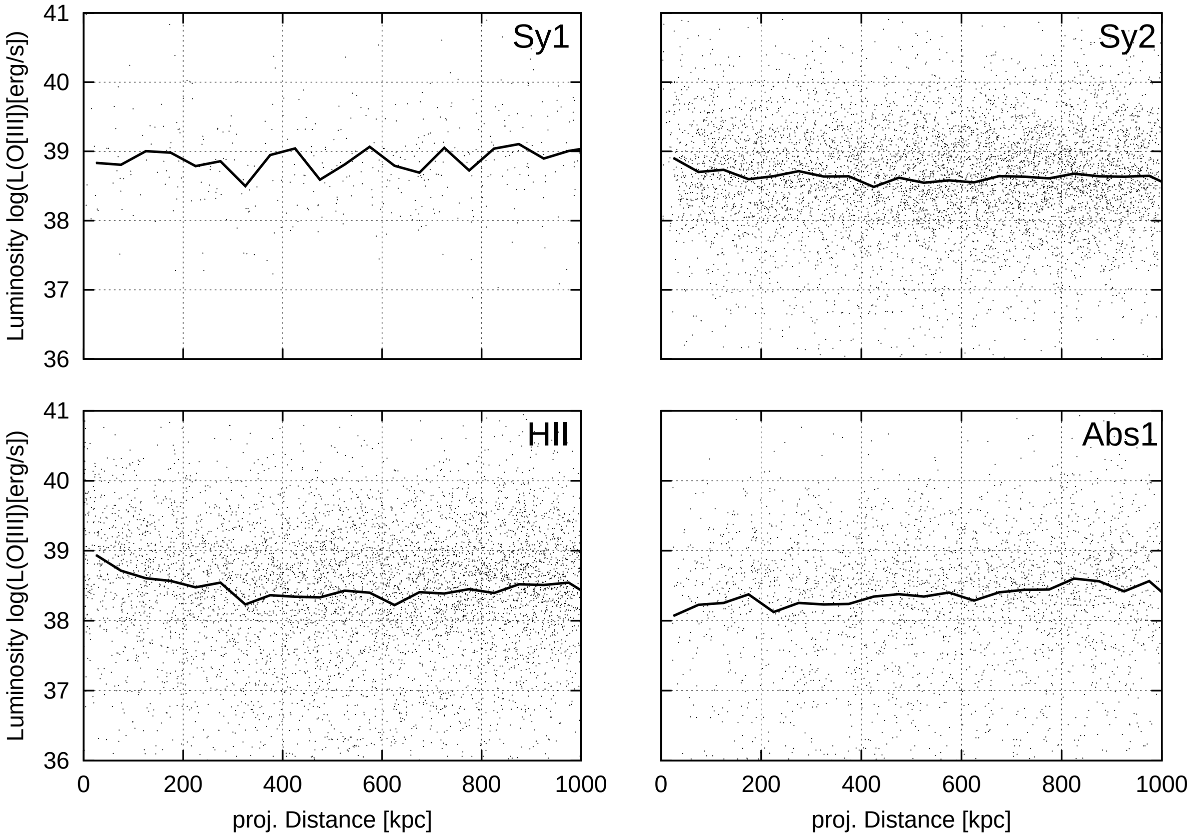

Fig. 3. [O III] λ5007 luminosity of the companion galaxies as a function of the distance to the central galaxy. The thick solid line shows the mean line intensities binned over intervals of 50 kpc projected distance.

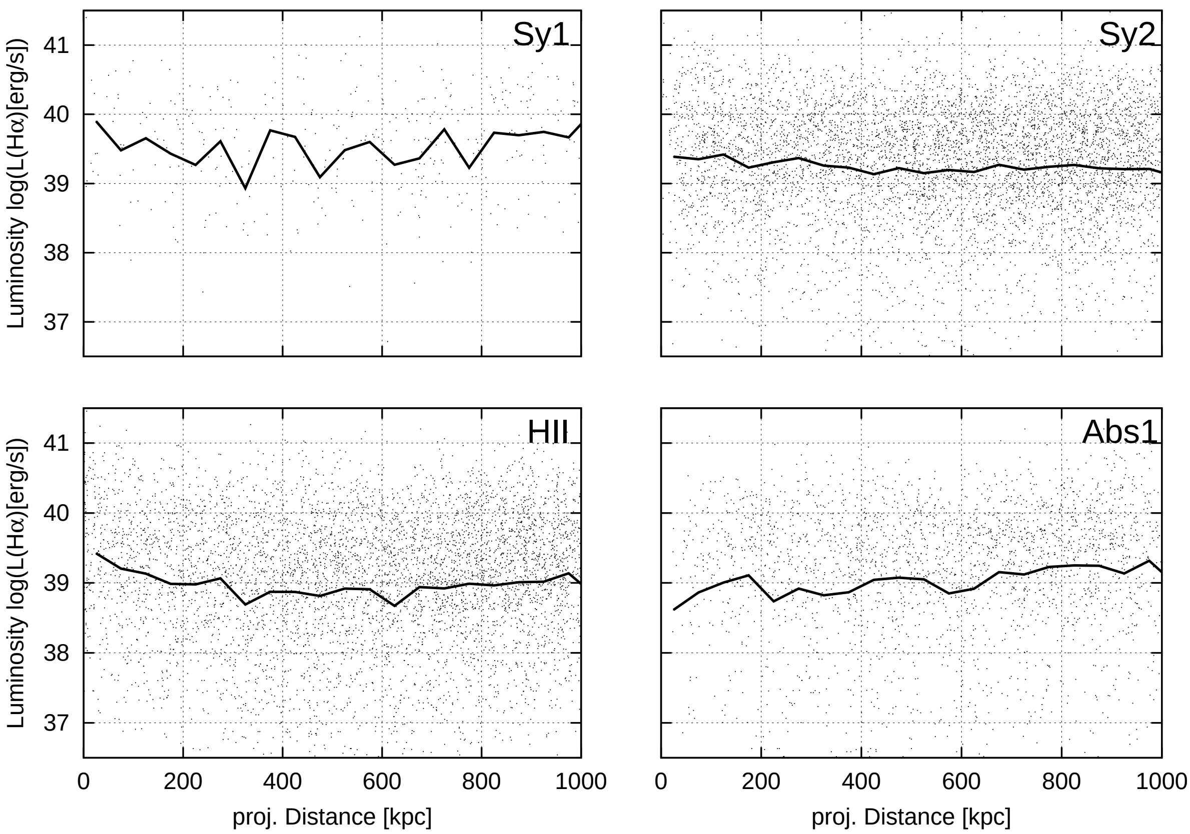

Fig. 4. Hα luminosity of the companion galaxies as a function of the distance to the central galaxy.

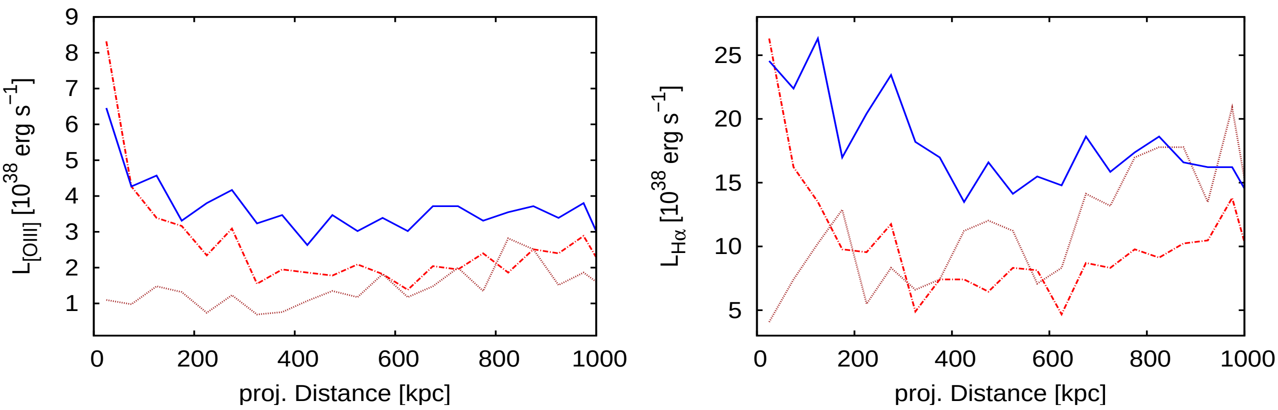

Fig. 5. Comparison of the [OIII] and Hα luminosities in the environmental galaxies around central Seyfert 2 (blue solid line), HII (red dot-dashed line), and absorption galaxies (brown dotted line) as a function of distance to the central galaxy.

Table 4. Log of mean Hα and [O III] λ5007 line luminosities (erg s^{-1}) of the central galaxies, as well as of the environmental galaxies within 1000 kpc.

activity type of centr. gal.	L(Hα) central	L(Hα) compan.	L(O[III]) central	L(O[III]) compan.
Sey1	41.48	39.64	40.64	38.94
Sey2	40.45	39.30	39.80	38.63
HII	40.61	39.09	39.89	38.52
Abs.	-	39.13	-	38.14

shells at distances of 0.-0.1 Mpc, 0.1-0.2 Mpc, 0.4-0.6 Mpc, as well as 0.8-1.0 Mpc.

The trend toward increasing/decreasing line luminosity as a function of distance does not apply to the continuum luminosities of the companion galaxies. Figure 6 shows the g-band continuum luminosities of the Seyfert 2 and HII companion galaxies as a function of the distance to the central galaxy. The definition of the magnitude μ is given by

$$\mu(x) = -a[sinh^{-1}(x/2b) + ln\ \ b]$$

where x is the dimensionless normalized flux $x = f/f_0$ and $a = 2.5/ln(10) = 1.08574$. The "softening" constant b determines the flux level at which linear behavior sets in (see Lupton et al. 1999 for details).

The relative g-band continuum luminosities of the Seyfert 2 and HII companion galaxies are independent of the distance to the central galaxy in contrast to the Hα and [OIII] line luminosities. The other Sloan continua bands show the same constant characteristics as the g-band continuum.

6. Discussion and conclusion

We investigated the spectral properties of the surrounding galaxies around central Seyfert/non-Seyfert galaxies in a large-scale projected environment of 1 Mpc. We restricted ourselves to galaxies having redshifts z of less than 0.08. Altogether, we analyzed the spectra of about 25,000 spectra from the Sloan Digital Sky Survey (SDSS).

Table 5. Log of mean [O III] λ5007 and Hα line luminosities (erg s^{-1}) in the environmental galaxies given for different types of central galaxies and for different spherical shells at different distances.

act.type centr.gal.	L(O[III]) 0–0.1 Mpc	L(O[III]) 0.1–0.2 Mpc	L(O[III]) 0.4 –0.6 Mpc	L(O[III]) 0.8–1.0 Mpc
Sey1	38.89	38.79	38.76	38.98
Sey2	38.70	38.55	38.49	38.51
HII	38.69	38.44	38.25	38.35
Abs.	38.07	38.00	38.11	38.28
act.type centr.gal.	L(Hα) 0–0.1 Mpc	L(Hα) 0.1–0.2 Mpc	L(Hα) 0.4 –0.6 Mpc	L(Hα) 0.8–1.0 Mpc
Sey1	39.68	39.35	39.42	39.78
Sey2	39.38	39.27	39.17	39.20
HII	39.25	38.98	38.84	38.99
Abs.	38.83	38.92	38.99	39.19

6.1. The number of companions as function of internal emission line and continuum intensities

We analyzed the environmental galaxies around 1,594 central AGN (47 percent), around 1,406 central HII galaxies (41 percent), and around 415 central absorption line galaxies (12 percent). The relative numbers of these central activity types are similar to those of a complete sample of nearby galaxies consisting of 486 galaxies (Ho et al., 1997). They identified 15 percent of their nearby galaxies as absorption line galaxies, 40 percent as HII nuclei, and 45 percent as AGN (including LINERs) (their Table 1).

We demonstrated that the number of companion galaxies is inversely correlated to the internal Hα and [O III] λ5007 line, as well as to continuum luminosities in projected environments of 1 Mpc around a central galaxy (Fig. 1). This universal trend is seen in all our samples independent of the activity degree of the central galaxy. The general results remained the same when we chose subsamples consisting of e.g. central galaxies with g-band magnitude limits of only 17.

Schmitt (2001) has investigated the immediate galaxy density distribution among galaxies of different activity types in an earlier study. He considered secondaries at distances five times the diameter of the primary. He found more immediate neighbors near absorption line galaxies. In the larger environment of absorption line galaxies, we detected more companions as

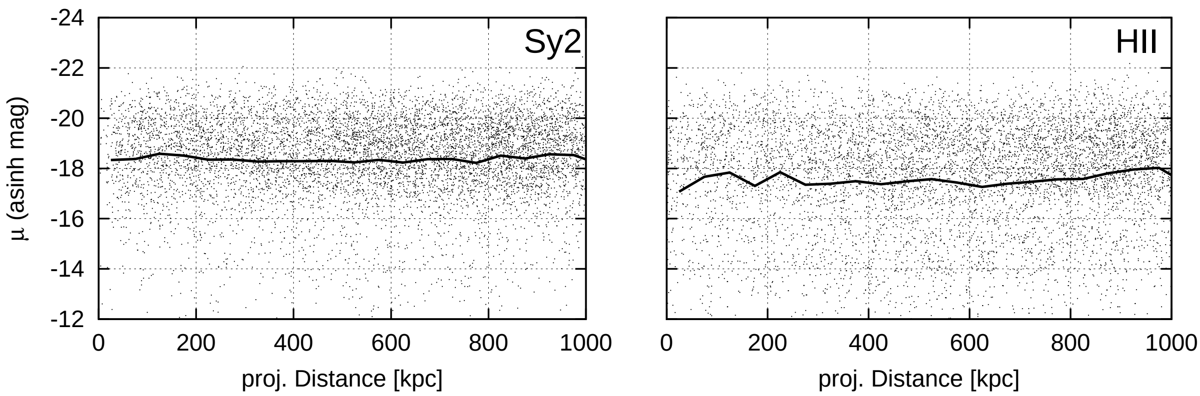

Fig. 6. g-band continuum luminosity of the Seyfert 2 and HII companion galaxies as a function of distance to the central galaxy.

well. Schmitt (2001) explains his finding with the morphology-density effect of different morphological galaxy types. However, Constantin & Vogeley (2006) carried out an independent investigation of the clustering of low-luminosity AGN. They also find that Seyfert galaxies are less clustered than normal galaxies. They claim that the clustering around AGN is not driven in a simple way by the morphology-density relation, since colors and concentration indices follow similar distributions.

Miller (2004) investigated the effect of galaxy environment on observed Hα emission line intensities in galaxies to derive their star-formation rate and AGN activity based on an early release of the SDSS. In analogy to the density-morphology relation, he presented a density-morphology-star formation relation. He found that the fraction of star-forming galaxies decreases in dense regions while the fraction of AGN is constant over all densities. He explains this result by the idea that the AGN phenomenon is mainly related to the bulge component of galaxies and does not depend to any great extent on the galaxy environment.

The cause for a general relation between emission line intensities and a lower number of companion galaxies should be a topic for future investigations. One idea for explaining this relation might be the limited amount of intergalactic gas that streams into the galaxies and leads to the formation of emission lines. This idea is similar to the picture of Dekel et al. (2009) that cold streams in massive halos are the main mode of galaxy formation.

The star formation rate in galaxies is driven partly by internal processes (gas consumption) and partly by local or large-scale environmental effects. Diaferio et al. (2001) discusses the concept that galaxies in groups or clusters that are not located at the center of their potential are assumed to have no hot gas reservoir for refueling the gas for star formation activity.

Wake et al. (2004) present two-point correlation functions (2PCF) of narrow-line AGNs. They show that their two-point correlation function depends on the [O III] line luminosities in their AGN. Low-luminosity AGNs have a higher clustering amplitude than high-luminosity AGNs. They consider their finding with the idea that low-luminosity AGNs reside in more massive galaxies and that the luminosity is an indicator for the fueling rate. In hierarchical models of structure formation, more massive dark matter halos are more strongly clustered.

The lower number of companion galaxies is inversely correlated to the continuum luminosities of the central galaxies as well. The continuum luminosity correlates very roughly to the mass of the central galaxy. This finding means that, on average, more massive galaxies are surrounded by fewer companion galaxies.

6.2. The number of AGN companions

Numerous studies about the number of AGN/QSO companions have been executed in the past. There are indications in some investigations that the AGN environment depends, among others, on the investigated scale around the AGN, on the cosmological distance of the objects, as well as on the AGN type. Miller et al. (2003) and Coldwell & Lambas (2006) analyzed the environment of a few thousand nearby AGN (z<0.2). They find similar number densities around AGN and local galaxies. Li et al. (2006) analyzed the clustering of narrow-line AGN (Kauffmann et al., 2003) in the local Universe too. They claim that on scales larger than a few Mpc, their narrow-line AGN have almost the same clustering amplitude as their control sample of inactive galaxies. On scales between 100 kpc and 1 Mpc their AGN are more weakly clustered, while they are marginally more strongly clustered on scales less than 70 kpc. Shirisaki et al. (2011) studied the AGN-galaxy clustering of 1809 AGN at redshifts from 0.3 to 3.0 using Subaru Suprime-Cam images and UKIDSS catalog data. At higher redshifts they find a significant excess of galaxies around AGN, while for lower redshifts (z<0.9) AGN resided in similar environments to the typical local galaxies. On the other hand, they detected that the majority of galaxies that are observed to be clustered around the AGN are blue star-forming galaxies. Based on 1800 nearby AGN Sorrentino et al. (2006) see no difference in the large-scale environment of Seyfert 1 and Seyfert 2 galaxies.

However, we found in our study (see Table 1) that Seyfert 1 galaxies have on average fewer companion galaxies than Seyfert 2 or HII galaxies within an environment of 1 Mpc. In a similar spirit, Koulouridis et al. (2006) uncovered the trend for the fraction of Seyfert 2 galaxies with a close neighbor to be significantly higher than for Seyfert 1 galaxy samples within projected distances of 100 kpc. They explained the difference by different morphologies of their host galaxies. Strand et al. (2008) explored the environment of AGN with respect to redshift, type, and luminosity. They find an increased overdensity of Seyfert 2 galaxies compared to Seyfert 1 galaxies on scales out to 2 Mpc in overlapping redshift ranges.

Seyfert 2 galaxies have more companions than Seyfert 1 galaxies does not accord with the standard unified model for AGN. This should be investigated in more detail in the future,

especially by studying the luminosities and the morphologies of the host galaxies in more detail.

6.3. The distant dependent activity degree of AGN/non-AGN galaxies

We demonstrated that the [OIII] and Hα line luminosities in the environmental galaxies are increasing towards the central Seyfert and HII galaxies (Figs. 3 to 5). These distant dependent line-intensity variations around Seyfert and HII galaxies are effective only for the emission line luminosities - not for the continuum luminosities of the galaxies (Fig. 6). The Seyfert 2 galaxies are on average slightly brighter in the continuum than HII galaxies (see Fig. 6). That trend in the continuum luminosities has been noted before for nearby galaxy by Ho et at. (1997): They also find that AGN are slightly brighter than HII galaxies in the blue continuum (their Fig. 3).

So far no thorough statistical analysis has been carried out of the emission line properties in the large-scale environment around AGN/non-AGN. Alonso et al. (2007) performed a statistical analysis of the [OIII] luminosities of AGN in pairs and AGN without close companions. They find that the [OIII] luminosity of AGN is correlated with the luminosity of the close companion galaxies ($r_{proj} \leq 25$ kpc).

However, we are investigating the large-scale environment of AGN and are looking for the activity degree of the environmental galaxies. We demonstrated that the emission line activity of the companions is getting stronger up to a factor of four within projected distances of 400 kpc around central Seyfert and HII galaxies. The same trend toward increasing emission line luminosity in the environmental galaxies as a function of projected proximity to the central AGN has been noted before by Kollatschny & Fricke (1989). This earlier study is based on a much smaller sample of only nearby Seyfert galaxies.

The observed distant dependent activity degree can be explained by mutual tidal triggering of Seyfert and starburst/HII activity. If the duration of the starburst is around $2 \cdot 10^8$ years (e.g. McQuinn et al., 2009 and references therein) and if the internal velocity dispersion in groups/clusters is around 1,000 $km\ s^{-1}$ (e.g. Barrena et al., 2011; Fadda et al., 1996), then both interacting partners might have moved away by 200 kpc on average. This distance covered within the lifetime of the starburst activity corresponds to the results seen in Fig. 5. It indicates that both the starburst and the Seyfert activity are triggered by tidal interaction and that the lifetimes of starburst and Seyfert activities are of the same order of magnitude.

Acknowledgements. This work is based on SDSS data. Funding for the creation and distribution of the SDSS Archive has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the U.S. Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is http://www.sdss.org/. The SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions. The Participating Institutions are The University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, the Korean Scientist Group, Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.

This work has been supported by the Niedersachsen-Israel Research Cooperation Programm ZN2318 and DFG grant Ko 857/32-1.

Note added in proof. In a recent publication, Haas et al. (2012) demonstrate a strong correlation between the number of galaxy neighbors and the host's dark matter halo. Combining their finding with our result indicates an inverse dependence of star formation and/or AGN activity on the host's halo mass.

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